

[illegible]

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General field of the invention

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The invention is particularly advantageous in application to rotary vibration motors, however it can also be applied to linear actuators, the term "vibration motor" in the present specification covering both rotary motors and linear actuators.

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force are interposed between the sectors 6 and these two inner plates 4. Spring-forming means 9 are interposed between the casing 2 and the contact sectors 6 of the outer plates 4.

When an active element 8 lengthens, the contact sectors 6 in register therewith clamp the rotor disks 1. When it retracts, the corresponding contact sectors 6 release the disks 1.

Two active elements 7 on either side of the same sector 6 are excited in phase opposition. Similarly, two adjacent active elements 8 are likewise excited in phase opposition. The active elements 8 for generating a normal force and the active elements 7 for tangential deformation are controlled synchronously so as to drive the rotors 1 in rotation.

State of the art and objects of the invention

One of the problems encountered with vibration motors is that of their efficiency.

Proposals have already been made to use a material having resilient properties in a reciprocating contact zone between a rotor and a stator so as to minimize energy dissipation associated with cyclic friction between the rotor and the stator.

In particular, French patent application FR 2 742 011 proposes using shape memory alloys which are materials having non-linear super-elasticity and which, compared with conventional materials, have the advantage of accommodating large amounts of deformation in small quantities of material.

The term "super-elasticity" is used throughout the present specification to designate the property whereby a material can accept reversible elongation of 1% or more. It is also recalled that the non-linear character of super-elasticity gives rise to the presence of a change-of-phase plateau in the curve of deformation as a function of traction force.

1990-1991		1991-1992		1992-1993		1993-1994		1994-1995		1995-1996		1996-1997		1997-1998		1998-1999		1999-2000		2000-2001		2001-2002		2002-2003		2003-2004		2004-2005		2005-2006		2006-2007		2007-2008		2008-2009		2009-2010		2010-2011		2011-2012		2012-2013		2013-2014		2014-2015		2015-2016		2016-2017		2017-2018		2018-2019		2019-2020		2020-2021		2021-2022		2022-2023		2023-2024		2024-2025		2025-2026		2026-2027		2027-2028		2028-2029		2029-2030		2030-2031		2031-2032		2032-2033		2033-2034		2034-2035		2035-2036		2036-2037		2037-2038		2038-2039		2039-2040		2040-2041		2041-2042		2042-2043		2043-2044		2044-2045		2045-2046		2046-2047		2047-2048		2048-2049		2049-2050		2050-2051		2051-2052		2052-2053		2053-2054		2054-2055		2055-2056		2056-2057		2057-2058		2058-2059		2059-2060		2060-2061		2061-2062		2062-2063		2063-2064		2064-2065		2065-2066		2066-2067		2067-2068		2068-2069		2069-2070		2070-2071		2071-2072		2072-2073		2073-2074		2074-2075		2075-2076		2076-2077		2077-2078		2078-2079		2079-2080		2080-2081		2081-2082		2082-2083		2083-2084		2084-2085		2085-2086		2086-2087		2087-2088		2088-2089		2089-2090		2090-2091		2091-2092		2092-2093		2093-2094		2094-2095		2095-2096		2096-2097		2097-2098		2098-2099		2099-2100		2100-2101		2101-2102		2102-2103		2103-2104		2104-2105		2105-2106		2106-2107		2107-2108		2108-2109		2109-2110		2110-2111		2111-2112		2112-2113		2113-2114		2114-2115		2115-2116		2116-2117		2117-2118		2118-2119		2119-2120		2120-2121		2121-2122		2122-2123		2123-2124		2124-2125		2125-2126		2126-2127		2127-2128		2128-2129		2129-2130		2130-2131		2131-2132		2132-2133		2133-2134		2134-2135		2135-2136		2136-2137		2137-2138		2138-2139		2139-2140		2140-2141		2141-2142		2142-2143		2143-2144		2144-2145		2145-2146		2146-2147		2147-2148		2148-2149		2149-2150		2150-2151		2151-2152		2152-2153		2153-2154		2154-2155		2155-2156		2156-2157		2157-2158		2158-2159		2159-2160		2160-2161		2161-2162		2162-2163		2163-2164		2164-2165		2165-2166		2166-2167		2167-2168		2168-2169		2169-2170		2170-2171		2171-2172		2172-2173		2173-2174		2174-2175		2175-2176		2176-2177		2177-2178		2178-2179		2179-2180		2180-2181		2181-2182		2182-2183		2183-2184		2184-2185		2185-2186		2186-2187		2187-2188		2188-2189		2189-2190		2190-2191		2191-2192		2192-2193		2193-2194		2194-2195		2195-2196		2196-2197		2197-2198		2198-2199		2199-2200		2200-2201		2201-2202		2202-2203		2203-2204		2204-2205		2205-2206		2206-2207		2207-2208		2208-2209		2209-2210		2210-2211		2211-2212		2212-2213		2213-2214		2214-2215		2215-2216		2216-2217	
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5 In above-mentioned patent application FR 2 742 011,
it is shown that such a structure has the advantage of
limiting the peaks of the applied normal force and of
maintaining the tangential friction force at values below
the slip threshold.

An object of the invention is to further increase
the efficiency of vibration motors.

10 Application EP 0 543 114 discloses an actuator in
which bearing contact between the fixed portion and the
moving portion is minimized so as to ensure that energy
losses due to friction are minimized. In the solution
proposed in that document, the contact surface of the
fixed part as constituted by the stator is not rigid, but
is deformed by the propagation of a traveling wave which
15 drives the moving part which constitutes the rotor. Only
the peak of the continuous deformation then comes into
contact with the driven part.

20 It will be understood that that solution does not
make it possible to obtain high drive powers of a kind
that would be obtainable from vibration motor structures
as described above with reference to Figures 1 and 2 and
operating on the principle of setting rigid sectors into
vibration which sectors are moved bodily and not by
continuous deformation.

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Brief summary of the invention

30 The invention proposes a solution for increasing the
efficiency of a vibration motor of the type comprising
comprising at least one stationary part and one part
driven to move relative to said fixed part, together with
excitation means suitable for exerting forces that tend
to move rigid contact sectors presented by said fixed
part and/or said moving part and to cause said rigid
sectors to vibrate in vibration modes that combine
35 tangential vibration and normal vibration, thereby
driving the movement of the moving part.

For the tangential vibrations or the normal vibrations, said motor presents a main resonant mode and at least one secondary resonant mode, and the proposed solution consists in that the secondary resonant mode is at a frequency which is substantially equal to a harmonic frequency of the main resonant mode.

In particular, the moving part can be a rigid disk rotor, said motor having a stator which comprises at least one pair of stator plates, each plate having rigid petals suitable for receiving means for displacing said rigid petals tangentially and normally.

In a variant, the motor can be a linear actuator.

In a first advantageous variant, at least one element having elastic deformation properties is included in the moving part and/or the stationary part, said element being separated from the contact face of said moving part and/or of said fixed part by a shoe-forming portion, and

the part(s) in which the elastic deformation elements are included is/are dimensioned in such a manner that the frequency of the secondary tangential resonant mode which is the resonant mode in which the shoe-forming portion and the remainder of the part oscillate in phase opposition, is substantially equal to a frequency which is a harmonic frequency of the main tangential resonant mode, in which the shoe-forming portion and the remainder of the part oscillate in phase.

Such a motor advantageously further includes the various following characteristics:

- the frequency of the secondary tangential resonant mode is substantially equal to twice the frequency of the main tangential resonant mode;
- it includes an array of elastic elements interposed between the shoe-forming portion and the remainder of the stationary part and/or the moving part; and

- the elastic element is made of a material presenting properties of super-elasticity.

In another, likewise advantageous variant, which can be implemented in addition to the first variant or independently thereof, the motor presents a secondary normal resonant frequency which is substantially a harmonic frequency of the main normal resonant frequency, and the excitation means comprise means for generating normal vibrations at both of these two resonant frequencies.

Such a motor advantageously further includes the various following characteristics taken singly or in any feasible combination:

- it comprises a casing containing at least two pairs of stator plates having tangential deformation active elements, and two rotor disks which extend between the plates of respective ones of said two pairs, the normal deformation active elements extending in particular between the plates of both of the two facing pairs, spring-forming means being interposed between the pairs of plates and the casing, and

it includes, between the stator plates and the spring-forming means, at least one assembly comprising a mass and an elastic deformation element, said assembly being dimensioned in such a manner that the frequency of the secondary resonant mode in which the stator plates and said mass oscillate in phase opposition, is substantially equal to an integer number of times the main resonant frequency in which the stator plates and said mass oscillate in phase, the excitation means including means for exciting normal deformation active elements at a frequency which is substantially equal to the secondary resonant frequency;

- an elastic deformation element is a normal deformation active element excited at a frequency substantially equal to the secondary resonant frequency;

- a normal deformation active element for the main resonant mode is excited by a signal which is the sum of a signal at the main resonant frequency plus a signal at the secondary resonant frequency;

5 - the secondary resonant frequency is substantially equal to an odd number of times the main resonant frequency;

- the secondary resonant frequency is substantially equal to three or five times the main resonant frequency;

10 - the frequency of the secondary resonant mode is equal to an integer number of times the main resonant frequency, with accuracy of the order of $\frac{1}{2Q}$ where Q is the lower of the quality factors of the two resonances; and

15 - it includes at least one assembly comprising a mass and a plurality of elastic deformation elements interposed between the stator plates and the spring-forming means, the elastic deformation elements being of stiffnesses such that said elements correspond to a plurality of harmonic resonant frequencies.

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Description of the figures

Other characteristics and advantages of the invention appear further from the following description which is purely illustrative and non-limiting and which should be read with reference to the accompanying drawings, in which:

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- Figures 1 and 2, described above, are diagrams respectively in cross-section and in axial section through a vibration motor constituting a possible embodiment of the invention;

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- Figure 3 is a diagram illustrating the zone between a moving part and a stationary part of a vibration motor;

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- Figures 5a to 5c are graphs showing variations as a function of time in the deformation of the various layers in Figure 3 (Figure 5a), of the slip speed between the layers (Figure 5b), and of the friction forces acting therebetween (Figure 5c);

- Figure 7 is a diagram showing a vibration motor structure constituting a possible embodiment of the invention;

- Figure 9 is a graph showing variation as a function of time in the bearing force between a rotor and a stator, firstly when controlled in accordance with the prior art (dashed line curve) and secondly when controlled in accordance with an embodiment of the invention (continuous line curve).

The invention is described below for a rotary motor, however it naturally applies in the same manner to a linear motor.

Figure 3 shows an example of a possible structure for a petal 6 in a structure of the type shown in Figures 1 and 2.

The petal 6 is constituted by a metal block having a main portion 12, a contact shoe 11, and an array of intermediate elements 10 interposed between the portion 12 and the contact shoe 11.

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By way of example, the intermediate elements 10 are
pegs of cylindrical or other shape, and suitable in
particular for accepting bending deformation.

5 In a variant, they can be constituted by blades, in
particular blades that are generally plane in shape,
extending at rest perpendicularly to the general plane of
the portion 12 and suitable, in particular, for deforming
elastically in bending under the effect of a force that
10 moves the contact shoe 11 relative to the portion 12
parallel to the general plane relative to which they
extend.

The elements 10 which constitute the elastic portion
interposed between the shoe-forming portion 11 and the
remainder of the stator (portion 12) is advantageously a
15 semicrystalline polymer, and in particular polyether
etherketone (PEEK).

Semicrystalline polymers, and in particular PEEK,
have the advantage of a low modulus of elasticity, large
elongation, excellent fatigue resistance, and good
20 temperature behavior.

When the elastic intermediate layer is made of such
materials, it can be constituted by a solid layer so that
it is easier to make.

25 The main portion 12, the contact shoe 11, and the
elements 10 can be molded as a single piece of material
that enables the elements 10 to present elastic
properties, e.g. a steel.

From the structure shown in Figure 3, it will be
understood that the elements 10 do not come directly into
30 contact with the rotor 1a or 1b, the petal 6 having a
portion 11 constituting a contact shoe which separates
said element 10 from the rotor 1a or 1b on which said
petal 6 comes to bear.

35 Such a structure is preferable to a structure in
which the pegs or blades 10 come directly into contact
with the rotor since that would give rise to tribological
problems and contact area would be reduced.

Nevertheless, the presence of the shoe-forming portion 11 changes the dynamic behavior of the motor because of its mass.

5 However, it has been found that by appropriately dimensioning the structure constituted in this way, and in particular by dimensioning the shoe-forming portion 11, it is possible to improve the efficiency of the structure.

10 As shown in Figure 4, such a structure can be modelled on examining the tangential oscillations generated on the shoe 11 by the vibrations generated on the active elements 7 as an oscillating system presenting:

- 15 - a first mass (portion 12 which constitutes the main portion of a petal 6);
- a first elastic element (array of elements 10);
- a second mass (shoe-forming portion 11); and
- a second elastic deformation element (active
20 element 7) connected to a stationary node N which corresponds to the zone located in the middle of an element 7 between two successive petals 6.

Such a system having two masses and two stiffnesses presents two modes of oscillation:

- 25 - the first mode (frequency F1) is the main tangential resonant mode in which the shoe-forming portion 11 and the remainder of the petal 6 (portion 12) oscillate in phase, the frequency of this tangential main resonant mode is selected as being the excitation frequency at which the motor is operated; and
30 - the second mode (frequency F2) is the secondary tangential resonant mode in which the shoe-forming portion 11 and the remainder of the petal 6 (portion 12) oscillate in phase opposition, in this mode, the amplitude of the oscillation of the portion 12 of the
35 petal is much smaller than the amplitude of the oscillation of the shoe-forming portion 11, since the mass of the portion 11 is smaller.

The inventors have found that the efficiency with which vibration is converted into continuous movement is greatly improved when the petals of the stators are dimensioned so that the frequency F2 corresponds to a harmonic of the frequency F1 ($F2 = NF1$, where N is an integer), and in particular when:

$$F2 = 2F1$$

In particular, it is desirable for this condition, $F2 = 2F1$, to be complied with to within better than 10%.

Dimensioning includes selecting the shapes and the masses of the various portions of the petals, the distribution thereof, and in particular the distribution of the elements 10, etc.

The curves given in Figures 5a to 5c show that under such circumstances, the speed of the shoe remains close to the speed of the rotor during a longer fraction of the cycle, thereby minimizing friction losses.

In Figure 5a, the curve Xt_{12} shows the tangential displacement of the portion 12 of a petal 6 while the curve Xt_{11} shows the tangential displacement of the corresponding shoe 11.

In Figure 5b, the curve shows the slip speed between the shoe 11 and the rotor it drives.

During a driving phase, the slip speed is minimized with the elements 10 and the shoe-forming portion 11 being dimensioned for increasing compliance with the condition $F2 = 2F1$; sticking takes place over a large fraction of this driving phase.

During the other phase of the cycle, the slip speed becomes negative.

Figure 5c shows how the friction force between the stator and the rotor varies over time.

Naturally, the invention applies in the same manner when the oscillating elements are not included in the stator but are included in the rotor, as shown in Figure 6.

The rotor is then dimensioned so as to enable $F2 = 2F1$.

5 Naturally, under all circumstances, the pegs or blades 10 are advantageously made of materials that present super-elasticity, and in particular linear super-elasticity.

Materials presenting non-linear super-elasticity such as shape memory alloys can also be envisaged.

10 It will be observed that the above description applies to the case of the preferred embodiment in which $N = 2$. Nevertheless, other harmonic values produce similar effects, but with reduced intensity. In addition, an odd harmonic would produce peak limiting effects not only in the right-hand portion of the slip speed (curve analogous to that shown in Figure 5b), but also in the left-hand portion thereof, but this is of no use.

Normal vibration modes

20 The vibration motor shown in Figure 7 is similar in structure to that shown in Figures 1 and 2 and the same reference numerals plus 100 are used to designate structural elements shown in Figure 7 that are the same as elements shown in Figures 1 and 2.

25 Thus, the structure shown in Figure 7 comprises a casing 102 containing two rotor plates 101 each interposed between two stator plates 104.

30 The stator plates 104 are constituted by metal petals 106 that are spaced apart by active tangential deformation elements 107.

35 A petal 106 is advantageously a metal petal having at least one elastically deformable element included therein. By way of example, the petal 106 includes an array of elements 122 such as pegs or blades in the vicinity of its surface, these elements 122 being preferably spaced apart from the contact surface of the petal by a shoe-forming portion thereof.

Normal deformation active elements 108 are interposed between the petals 106 of the inner two stator plates 104 (i.e. the two stator plates which are situated between the other two, which other two are referred to as "outer" stator plates).

Spring-forming means 109 are interposed between the casing 102 of the motor and the petals 106 of the two outer stator plates 104.

More precisely, each petal 106 of the outer stator plates carries a complementary mass 120 which is mounted on said petal via a normal deformation active element 121 (e.g. made of piezoelectric material), the spring-forming means 109 bearing against said mass 120.

Such a structure can be modelled as an oscillating system presenting:

- a first mass (the mass 120);
- a first elastic deformation element (the active element 121);
- a second mass referenced 123 (corresponding to two petals 16 on either side of the portion of the rotor 101 corresponding thereto); and
- a second elastic deformation element (portion of an element 108 which extends between said mass 123 and the midplane N of the elements 108, said midplane being considered as a fixed node of the system).

Such a system with two masses and two stiffnesses present two modes of oscillation:

- the first mode (frequency F1) is the main normal resonant mode in which the masses 120 and 123 oscillate in phase; the frequency of this resonant mode is selected as being the excitation frequency for the tangential and normal deformation active elements 107 and 108, the motor having excitation means for this purpose; and
- the second mode (frequency F2) is the secondary normal resonant mode in which the masses 120 and 123 oscillate in phase opposition.

The mass 120 and the active element 121 are dimensioned (shape, mass, material, etc.) so that the frequency $F2$ is equal to $N \times F1$ where N is an integer, and the motor has means for exciting said active element 121 at said frequency $F2$.

Advantageously, N is selected to be odd.

The thrust force then obtained is that shown in Figure 9 (continuous line curve C1) which is substantially peak limited compared with the curve obtained by exciting only the active elements 107 and 108 at the frequency $F1$ (dashed line curve C2).

It will be observed that when N is even, the peak limiting effect is also obtained, but on one side of the cycle only, only the top portion being peak limited.

In particular, it is preferable to select $N = 3$ or $N = 5$, small-order harmonics providing larger effects.

Nevertheless, it is possible for N to have values other than $N = 3$ or $N = 5$.

Because the normal mode is damped much less than the tangential mode, the relationship $F2 = NF1$ ought preferably to be achieved with great accuracy. It is estimated that the necessary accuracy is about $\frac{1}{2Q}$ where Q represents the lower of the quality factors of the two resonances.

A variant of the solution described above consists in replacing the active element or block 121 by an equivalent passive stiffness and in feeding the main actuator with excitation at a frequency $NF1$ in addition to its fundamental excitation at the frequency $F1$.

Furthermore, in another advantageous variant, a plurality of elastic deformation elements 109 can be provided between a mass 120 and the remainder of a petal 106 said elements having different stiffnesses and consequently corresponding to different secondary resonant modes, said elements being selected so that

their frequency corresponds to a harmonic of the main frequency.

By combining the excitation frequencies corresponding to these various harmonics, it is possible to obtain normal bearing forces that are even more peak limited than as shown in Figure 9.

It is possible to envisage numerous other variant embodiments enabling a main resonant mode at at least one secondary resonant mode to be provided such that their respective resonant frequencies satisfy $F2 = NF1$.